

THE COPPER ORES OF MARYLAND

A DISSERTATION

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BY

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A METALLOGRAPHIC STUDY OF THE COPPER ORES OF MARYLAND.

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INTRODUCTORY.

Copper has been mined in Maryland since pre-Revolutionary days. Before the discovery of the large western deposits and the consequent drop in the price of copper, copper-mining was an industry of some importance in the State. Eight mines in all have been worked at one time or another: six of these were abandoned at least twenty-five years ago; and one is still worked, but only occasionally. Although no figures are available giving the total output of copper from the state, a production of \$1,750,000 from one of the mines over a period of twenty-five years will give a general idea of the former importance of copper-mining in Maryland.

An investigation of these deposits was undertaken with the hope that a microscopic examination of the ores might reveal something of the genesis of the deposits, and also add something to the general knowledge of the genesis of copper ore. In particular the object of the work was to study the structural relationships existing among the copper minerals in the ores, especially with regard to the question of the primary or secondary occurrences of bornite, chalcopyrite, and chalcocite. Certain difficulties connected with the work prevented its being as complete as could be desired, the chief of which were the impossibility of underground observation and the scarcity of good material. A close study of thin sections of country and of vein rock, however, and a very careful search of the mine dumps eliminated some of these difficulties.

The description of the deposits will be taken up in the follow-



ing order: (1) The Bare Hills mine; (2) the Eastern Carroll County mines, comprising the Patapsco mine, the Mineral Hill mine, and the Springfield mine; (3) the Frederick County mines, comprising the Liberty Mine, and the New London, or Linganore mine.

DETAILED DESCRIPTION OF MINES.

Baltimore County Mine, Bare Hills Mine.

The Bare Hills copper mine is located about 4 miles north of Baltimore on the northern outskirts of the suburb of Mt. Washington. A small mine dump is all that remains to mark the site of the old mine, last worked about thirty years ago.

The deposit, according to old descriptions, was in a vein which carried chalcopyrite, bornite, and magnetite. Unfortunately the material on the mine dump has so succumbed to attacks of the weather that ore and gangue minerals sufficiently fresh for microscopic study could not be obtained.

The deposit occurs in a general region of hornblende schist, probably an altered gabbro. A few hundred yards to the east lies a small serpentine mass that has been intruded into the schist. The ore is apparently in a vein conforming in strike to the schistosity of the rocks; and, as far as can be judged from general relationships and from the kind of material found on the dump, the deposit is similar in all respects to the copper occurrences of eastern Carroll County, which will be taken up in detail in the following pages.

The Eastern Carroll County Mines: the Finksburg-Sykesville Belt.

If a line be drawn on the map from Finksburg, Carroll County, in a direction S. 35° W., most of the copper mines and prospect holes giving evidence of copper will lie very close to this line. At the northern end is the Patapsco mine at Finksburg; 4½ miles southwest of Finksburg is the Mineral Hill mine, between the two is one prospect hole showing copper; 1 mile southwest of Mineral Hill an opening shows the presence of chalcopyrite, and a half

mile farther on at the point where the line crosses the state road, copper stains were noticed when the road was being built; a little farther on are a number of prospect holes, still on the same line. To include the southernmost deposits (those in the neighborhood of Sykesville), the line must be allowed to swing slightly to the south. If this is done, the Carroll mine and the Springfield mine, together with the intervening openings, fall into place. Several former iron mines are also found in Howard County on the southern extension of this belt.

An interesting feature of this belt of deposits is the relationship between the iron and the copper ores. In general iron ore is present in all the mines. On the southernmost extension of the belt in Howard County iron was mined, but no copper. The Springfield mine was opened as an iron mine; at a depth of between 60 and 100 feet enough chalcopyrite came in to change the character of the ore to a copper ore. The iron in the outcrop was in the form of specularite, but with depth it seems to have been largely magnetite. At Mineral Hill both iron and copper were found, but copper was much nearer the surface than was the case at Springfield. Magnetite predominates here. At the Patapsco mine copper ore occurs at the surface, together with much magnetite.

Patapsco Mine.

Location.—The Patapsco mine, the most northern of the eastern Carroll County group of mines, lies at the eastern end of the village of Finksburg, a few yards north of the Westminster turnpike. The nearest railroad station is Falls, on the Western Maryland Railroad, 23 miles from Baltimore. A small mine dump and a depression over the old shaft are all that remain to mark the site of the mine.

Geology.—All the copper mines of Maryland lie in that part of the state known geologically as the Piedmont Region. The characteristic features of Piedmont geology are so well known that a discussion of them here would be out of place. The rocks, in general, consist of schistose sedimentary and igneous rocks; and of unmetamorphosed igneous rocks intruded into the schists.

The prevailing rock of the general region in which the Patapsco mine lies is a quartz mica schist which, in the immediate neighborhood of the mine, has most of the characteristics of a phyllite. A thin section of this rock shows it to consist largely of fine-grained anhedral quartz with much biotite, sericite, garnet, and magnetite. The nature of the minerals present and their relationships suggest at once an original sedimentary origin for the schist. An examination of the rock making up the mine dump, however, shows it to be of an entirely different character from that of the country rock; for here are exposed amphibole and biotite schists. The contact between these two kinds of rock is effectually concealed, although the occurrence of weathered amphibole schist on the road-side about 100 yards east of the mine shows the existence of this rock for the distance mentioned at least.

A microscopic study of the rocks found on the mine dump was undertaken in order to determine, if possible, their nature before metamorphism. A thin section of the biotite schist showed it to consist entirely of flakes of greenish biotite in an unaltered condition. There are several types of hornblende schist, one of which consists almost entirely of common hornblende with small amounts of magnetite and biotite; and another of which is made up of common hornblende, zoisite, some plagioclase feldspar, quartz, and much epidote which replaces the hornblende and is evidently a product of the decomposition of feldspar and hornblende.

The rock appears to be derived from a basic igneous rock, and is probably a metagabbro. Aside from the schists, a small amount of pegmatitic material was found, which from its unaltered nature and from its relation to the schists evidently had its origin after the schists were formed. It has a miarolitic texture, and crevices which intersect it are lined with zeolites.

About all that can be said on the geological structure of the region around the mine is that the schists have a general strike N. 30° E. with a nearly vertical dip that varies from east to west.

Type of Deposit.—The copper ore, according to Tyson¹ who

¹ First Report of Philip T. Tyson, State Agricultural Chemist, to the House of Delegates of Maryland, Doc. E, February 12, 1860.

was writing at the time the deposit was being worked, was found in a "true vein" that "became thinner, or pinched off" with depth. The ore mined consisted of chalcopyrite, bornite, chalcocite, and carrollite, together with their oxidation products, and much magnetite.

Description of the Ore.—The description of the ore will be considered under two heads: first, the relation of the ore minerals to gangue minerals as shown in thin sections; and, second, the relations that exist among the opaque minerals as revealed by the study of polished sections.

The copper-bearing minerals—chalcopyrite, bornite, and carrollite—were found both in the biotite and the hornblende schists, and in the pegmatitic material: chalcopyrite being found in both schist and pegmatite; bornite being confined largely to the pegmatite rock; and carrollite² to the schist near the contact with pegmatite. Magnetite is present in the schist in large amounts closely associated with the copper minerals. An examination of the thin sections shows that, with the possible exception of some magnetite, all the opaque minerals are later than the transparent minerals present. The magnetite appears to be of two ages: part of it, occurring as sharp crystals and as grains in hornblende, being at least as old as the hornblende; and part of it being decidedly later than the hornblende. Fig. 1, shows chalcopyrite and bornite replacing hornblende, chlorite, and calcite; Fig. 2, is an excellent illustration of the replacement of epidote and feldspar by bornite.

A microscopic examination of polished sections of the ore brings out the relationships that exist among the ore minerals, and between ore minerals and gangue. The opaque minerals will be treated here in the approximate order in which they came out of solution.

Magnetite.—Magnetite, the earliest of the opaque minerals to crystallize, occurs in closely packed grains and in sharp or slightly rounded crystals. Although, as pointed out above, the magnetite is of two distinct ages of formation, by far the greater part is

² Carrollite— CuCo_2S_4 , a very rare cobalt mineral first described from the Patapsco mine.

EXPLANATION OF PLATE VIII.

FIG. 1. *The Mineral Hill Mine.* ($\times 47$.) Thin section showing chalcopyrite and bornite (both black) replacing hornblende (the mass of the slide) and chlorite (large light flake near upper left-hand corner).

FIG. 2. *The Patapsco Mine.* ($\times 47$.) Thin section showing replacement of epidote (rough surface) and feldspar (upper part of picture) by bornite (black).

FIG. 3. *The Mineral Hill Mine.* ($\times 60$.) Polished section. Inclusions of bornite (*b*) and chalcopyrite (*cp*) in a large magnetite (*mt*) crystal. The presence of both bornite and chalcopyrite in the same inclusion in the magnetite crystal shows their contemporaneity. Note the parallel or perpendicular arrangement of the rod-like inclusions. (Cf. Fig. 12.)

FIG. 4. *The Patapsco Mine.* ($\times 320$.) Polished section. Chalcopyrite (*cp*) is shown here in contact with a magnetite (*mt*) crystal. The corrosion and the rounding of the corners of the magnetite crystal indicate that the magnetite crystallized before the copper minerals came out of solution.

FIG. 5. *The Patapsco Mine.* ($\times 375$.) Polished section. This section shows a triangular inclusion in sphalerite (*se*), of bornite (*b*) and chalcopyrite (*cp*). Graton and Murdoch call attention to such triangular inclusions of chalcopyrite in sphalerite and suggest that they are sphenoidal crystals of chalcopyrite. The inclusion in this case is probably not a crystal. Covellite (*cv*) and chalcocite (*cc*) are seen replacing the sphalerite.

FIG. 6. *The Mineral Hill Mine.* ($\times 70$.) Polished section. Typical ore consisting of chalcopyrite (*cp*), bornite (*b*), magnetite (*mt*), and secondary chalcocite which replaces bornite and chalcopyrite along crevices. The chalcopyrite and bornite show typical primary relationships.



FIG. 1.

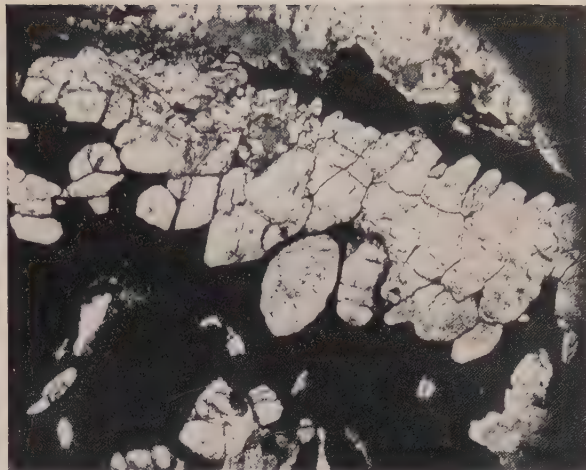


FIG. 2.

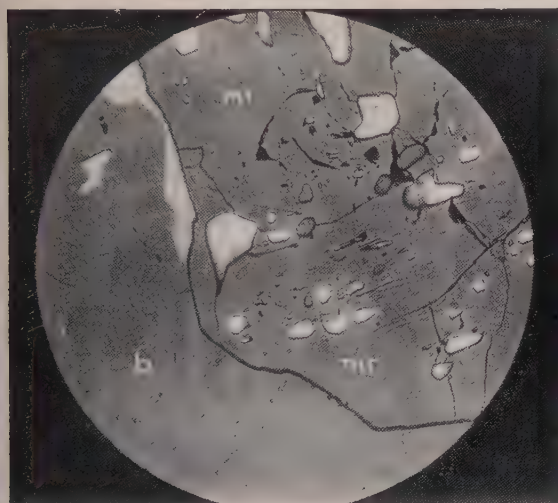


FIG. 3.

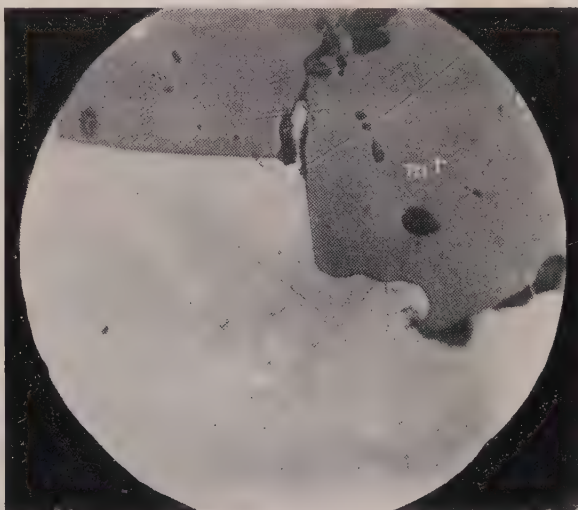


FIG. 4.

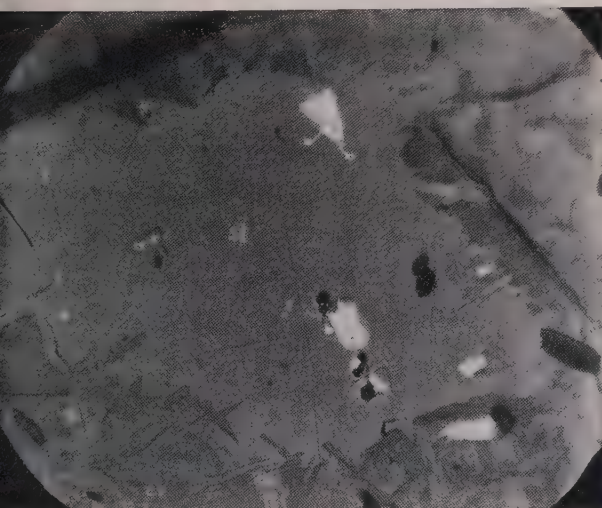


FIG. 5.

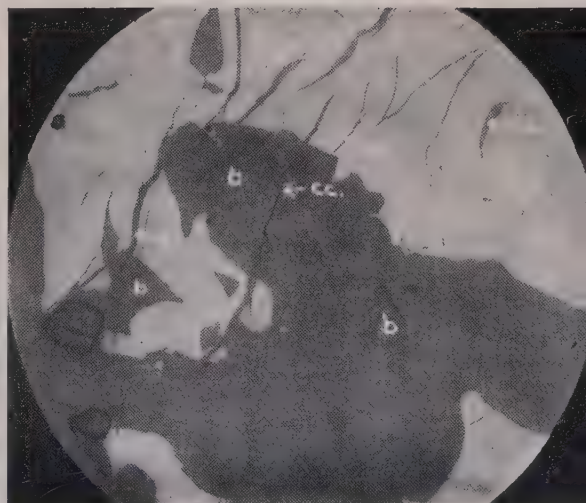


FIG. 6.

later than the schist in which it is found. A typical sample of the copper ore in which magnetite is present shows the following arrangement of minerals: first, a mixture of magnetite and schist in which the magnetite is both earlier and later than the gangue minerals; then a band of closely packed rounded grains of magnetite; next, a band of large well-formed magnetite crystals which are surrounded, or partly surrounded, by bornite and chalcopyrite, and which include numerous grains of the copper-bearing minerals. The facts, then, concerning the occurrence of the magnetite warrant the conclusion that it was the first of the opaque minerals to crystallize, and that some of it at least crystallized out of copper-bearing solutions. Fig. 3, shows inclusions of chalcopyrite and bornite in magnetite. The rounding of several of the crystals that are in contact with the copper minerals suggests a slight change in physical chemical conditions just after the crystal was formed. Fig. 4, is at a contact between chalcopyrite and magnetite, showing rounding and corrosion of the magnetic crystal.

Specularite.—Specularite, occurring in a narrow band, was noted in only two places, both of which were in the pegmatitic ore. In one case it distinctly replaces quartz; in the other case, in which it is surrounded by copper minerals, it is greatly corroded. Its relations to magnetite could not be determined, although it is evidently earlier than the copper-bearing minerals.

Carrollite.—Carrollite (CuCo_2S_4) occurs in such small amount and in such unfavorable surroundings that little that is definite can be said about it. It is evidently later than magnetite, but its relations with bornite and chalcopyrite are somewhat uncertain. The fact that it has roughly cubical outline, and that in one case chalcopyrite seems to be included in it would indicate that it is somewhat earlier than the other copper minerals present. The crystals are much fractured; chalcocitization has taken place along the fractures.

Sphalerite.—Since sphalerite occurs here in only very minor amounts, its discussion will be reserved for the Mineral Hill ores, where its relations to the other minerals can be more clearly observed. In the Patapsco ore it seems to be restricted to the peg-

matitic material, and occurs as irregular masses that have been altered largely to chalcocite and covellite. Fig. 5, shows sphalerite altering to chalcocite and covellite, and including chalcopyrite and bornite. The sphalerite is earlier than the chalcopyrite and bornite.

Chalcopyrite and Bornite.—Chalcopyrite and bornite are for the most part contemporaneous in origin. They show a typical primary intergrowth, both forming irregular masses that are intimately related. (See Fig. 6.) No secondary bornite was observed, although a little secondary chalcopyrite is present. The occurrence of secondary chalcopyrite developing along cleavage lines of bornite has been described and illustrated by Graton and Murdoch.³ Fig. 7, and Fig. 8, show this type of alteration. In Fig. 7, the gash-like structures are chalcopyrite surrounded by narrow bands of chalcocite; the main body of the slide, aside from gangue, is bornite. The thin dark line from which the gashes seem to start is a small crevice in the ore. In Fig. 8, the alteration bands narrow where they cross one another and swell out in the intervening space. The points of interest about the occurrence of this type of alteration are its limitation to contacts and to crevices in the ore, or to their immediate neighborhood, and its close association with chalcocite. The chemistry of this alteration has not been worked out.

Covellite.—Covellite is relatively widespread through the slides, where it is found accompanying chalcocite. Its usual appearance is in bunches or in feathery crystals within the chalcocite or at its contact with some other mineral. It is particularly abundant as a replacement mineral of sphalerite, its small crystals being so oriented as to conform in large part to the cleavage directions of the sphalerite. Fig. 5, shows a mass of sphalerite almost completely altered to covellite and to chalcocite. It shows also that the sphalerite is much more susceptible to alteration than is the included chalcopyrite.

Chalcocite.—All the chalcocite observed from this mine is clearly secondary, since it is found replacing all the opaque min-

³ Graton and Murdoch, "The Sulphide Ores of Copper," *Trans. Amer. Inst. Min. Eng.*, Vol. XLV., 1914, pp. 44, 49.

erals present except magnetite. Replacement has gone on largely in the vicinity of crevices in the ore, and at the contact between ore minerals and gangue, although, in the case of sphalerite, practically the whole mass has been altered. The contact between chalcocite and the altered mineral may be sharp or it may be fuzzy, the fuzziness being due in some cases to the presence of small feathery covellite crystals. The boundary lines between masses of ore minerals appear to be important places for the development or limitation of chalcocite; for often a crevice bordered by chalcocite will stop short at a contact, and sometimes, especially in passing from chalcopyrite to bornite or to sphalerite, the band will widen out. Fig. 9, brings out these points very strikingly. Fig. 10, shows the widening of a band of chalcocite on passing from chalcopyrite to bornite. It is interesting to note the unaltered grain of chalcopyrite within the chalcocite band. Under the condition of chalcocitizations of these deposits, then, it is evident that sphalerite is the most easily altered, that bornite is less so, and that chalcopyrite is the least susceptible to alteration.

The paragenesis of the opaque minerals of the Patapsco mine, then, seems to be magnetite (the oldest), carrollite, sphalerite, chalcopyrite and bornite, secondary chalcopyrite, covellite, and chalcocite. Of these magnetite, carrollite, sphalerite, and bornite are in all cases primary; chalcopyrite is largely primary, but also occurs as a secondary mineral; covellite and chalcocite are in all cases secondary. The opaque minerals are all later than the gangue, with the possible exception of a little magnetite which is earlier.

Mineral Hill Mine.

Location.—Four and one half miles southwest of Finksburg on the north side of Morgan Run, one half mile east of the state road crossing, lies the Mineral Hill mine. A rather large mine dump and a number of shallow pits show the location of the mine, which was last worked about 25 years ago.

Geology.—Geologically this occurrence of copper ore is similar to that at the Patapsco mine. The country rock to the east and

to the west consists largely of hard gray quartzose schists, which sometimes become rather micaceous, and then usually carry garnets; and sometimes very quartzose, consisting chiefly of large bands of quartz, 4 or 5 inches thick, separated by narrow micaceous stringers. These schists strike uniformly between N. 35° E. and N. 45° E., and have almost vertical dips. Pegmatite was not found with this ore as at the Patapsco mine; but just to the east of the mine the quartz schist is injected with pegmatitic material. A thin section of the country rock shows it to be similar to that of the Patapsco mine.

Here again, the material on the mine dump and from the outcrops in the immediate vicinity of the mine are seen to be of a different character from that of the country rock. Biotite, amphibole, chlorite, and talc schists comprise most of the rocks found on the dump; and chlorite and talc schists make up the actual outcrops at the mine. The biotite schists were seen under the microscope to consist almost entirely of biotite; the amphibole schists of common hornblende (altering in many cases to chlorite, talc, and epidote), zoisite, some quartz, and magnetite. A common rock noted at this mine was talc schist containing many beautiful little crystals of actinolite which under the microscope cut sharply across the plates of talc and undergo alteration to talc only at the ends or at places where a crystal had been bent and broken. This rock was not seen at the Patapsco mine, but it occurs to the south at the Springfield mine. Epidote is present in large amounts in all the slides, and appears to have been one of the latest minerals to form.

Type of Deposit.—Since the underground workings of the Mineral Hill mine are no longer accessible, it is necessary to depend on old reports for information concerning conditions underground. The ore is described as being in a vein 2 to 6 feet wide, which conformed in strike and dip with the schist. The northern end of the vein ran into the pre-Revolutionary workings, and apparently was not followed; the southern extension was cut out by talcose schist. The walls of the vein were of talcose and mica schist; the gangue was chlorite. Both copper ore and iron

ore occurred, the copper ore occupying the hanging wall side of the vein, the iron ore the foot wall side. The values were not distributed evenly, but occurred in shoots.

Description of Ore.—An examination of thin sections showed that the relations between the rock minerals and between ore and gangue is in all respects similar to the relations that exist at the Patapsco mine. The chief differences noted were the absence of pegmatite material at the Mineral Hill mine, and the greater abundance there of chlorite and talc schists. Magnetite is again present in large amounts, part of it being primary and part being introduced after the rock had formed. Bornite and chalcopyrite everywhere replace all the rock-forming minerals present with the possible exception of talc. Epidote is in most cases seen replacing hornblende and feldspar, and being replaced in turn by copper minerals. Zoisite appears to be one of the early constituents of the country rock, and probably was formed under the action of regional metamorphosing forces. Fig. 11, shows bornite replacing epidote, and surrounding quartz and feldspar.

Polished sections of ore from the Mineral Hill mine show that the ore minerals (and their relations to one another) are similar to those described from the Patapsco mine, and, consequently, little can be said other than that already stated.

Magnetite.—Magnetite is again primary and secondary (in the sense that it is later than the schist), and was the earliest of the opaque minerals to crystallize. Fig. 3, has already been used to illustrate the character of inclusions in magnetite. Fig. 12, gives a more highly magnified view of some of the inclusions. The large one near the center of the picture shows a grain of chalcopyrite with secondary magnetite within it, and within the secondary magnetite a still smaller grain of chalcopyrite.

Carrollite.—Carrollite shows roughly cubical outline, and contains some inclusions of chalcopyrite. It is apparently earlier than the chalcopyrite.

Sphalerite.—As at the Patapsco mine, sphalerite is later than

EXPLANATION OF PLATE IX.

FIG. 7. *The Patapsco Mine.* ($\times 365$.) Polished section. This section shows the alteration of bornite (*b*) to chalcocite (*cc*) along crevices and at the contact with gangue (*G*), (feldspar) and to chalcopyrite (*cp*) along cleavage lines. (Cf. Fig. 8.)

FIG. 8. *The Patapsco Mine.* (ca. $\times 600$.) Polished section. This section shows the alteration of bornite (*b*) to chalcopyrite (*cp*) along cleavage lines. A narrow band of chalcocite (*cc*) intervenes between the two minerals. It is interesting to note that the gash-like replacement or alteration bands become narrow where two bands cross, instead of broadening out as should be expected, if ordinary replacement were taking place.

FIG. 9. *The Patapsco Mine.* ($\times 87$.) Polished section. Here chalcocite (*cc*) and covellite (*cv*) replace bornite (*b*), chalcopyrite (*cp*), and sphalerite (*se*). The section shows the extent to which alteration and replacement have taken place in the different minerals. The sphalerite is almost completely altered to covellite and chalcocite; bornite has altered along crevices to rather wide bands of these minerals whereas the chalcopyrite shows only slight replacement along these same lines. (Cf. Fig. 10.)

FIG. 10. *The Patapsco Mine.* ($\times 380$.) Polished section. This shows the widening of an alteration band of chalcocite (*cc*) on passing from chalcopyrite (*cp*) to bornite (*b*). Note the unaltered bit of chalcopyrite included within the band of altered bornite.

FIG. 11. *The Mineral Hill Mine.* ($\times 47$.) Thin section showing bornite (black) surrounding and replacing epidote (mass of slide). The light areas are plagioclase feldspar.

FIG. 12. *The Mineral Hill Mine.* ($\times 320$.) Polished section. This is a more highly magnified picture of Fig. 3, showing inclusions of bornite (*b*) and chalcopyrite (*cp*) in magnetite (*mt*).

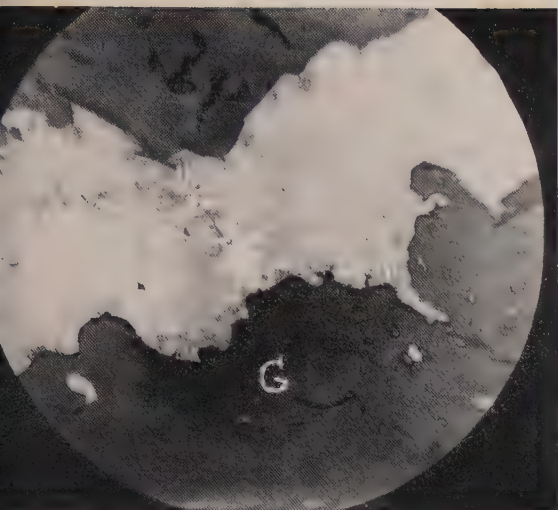


FIG. 7.

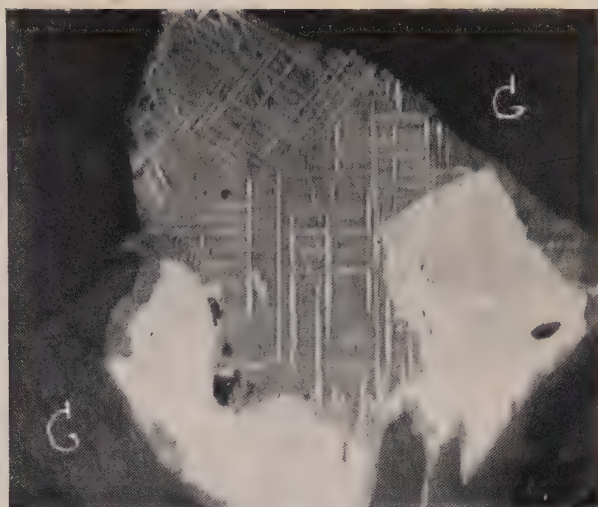


FIG. 8.

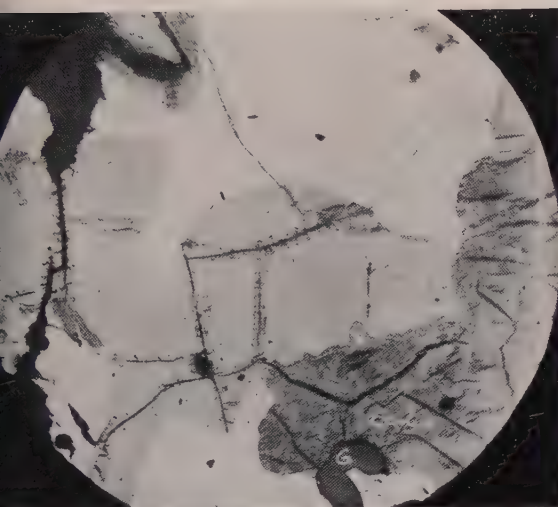


FIG. 9.

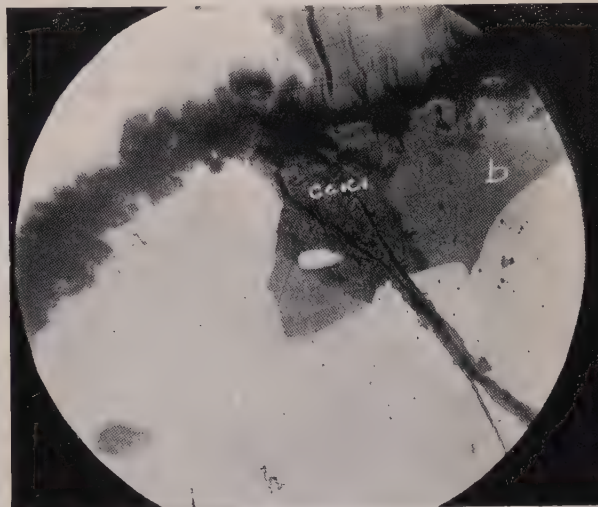


FIG. 10.

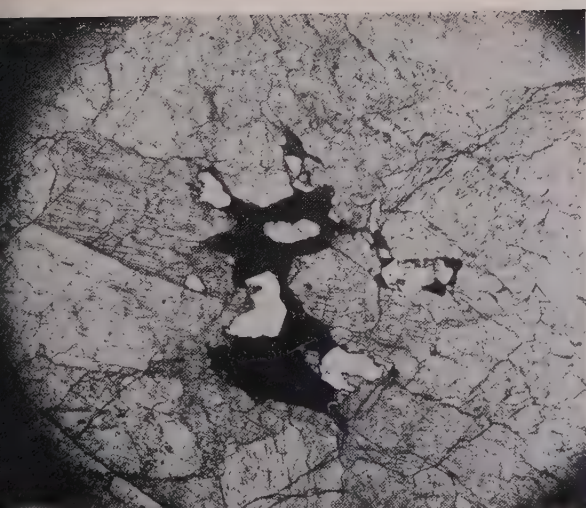


FIG. 11.

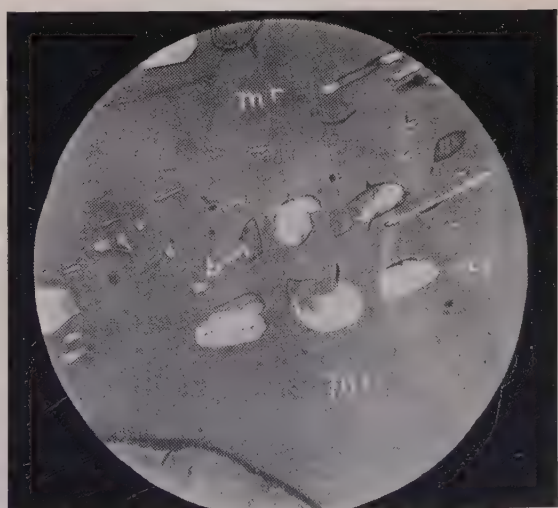


FIG. 12.

magnetite and earlier than chalcopyrite and bornite. Inclusions of chalcopyrite and bornite are exceedingly numerous, and are of two kinds: relatively large masses of the copper minerals, and small particles of chalcopyrite and bornite, which under the highest power of the microscope are seen to be definite geometrical figures—rectangles, trapezoids, and triangles predominating. Graton and Murdoch⁴ call attention to the existence of inclusions of chalcopyrite possessing triangular outline, and suggest that they are probably sphenoidal crystals. Such a triangular inclusion is seen in Fig. 5. The inclusion here shown consists of a mixture of bornite and chalcopyrite, and appears not to be a crystal. Fig. 13, shows sphalerite altering to chalcocite along cleavage lines; the small white spots scattered through the slide are inclusions in the sphalerite.

Chalcopyrite and Bornite.—Chalcopyrite and bornite show typical primary intergrowth, and are contemporaneous. Both are altered to chalcocite along the numerous fractures in the ore. Fig. 14, shows the character of alteration.

Chalcocite.—Chalcocite, as has just been said, is present in rather large amount, and is always secondary. It differs from the chalcocite present in the Patapsco ore in that it does not show a fuzzy contact with the altered mineral.

Covellite was not observed.

The paragenesis of these minerals, is the same as that for the Patapsco minerals: namely, magnetite (the oldest), carrollite, sphalerite, chalcopyrite and bornite, and chalcocite.

Between the Mineral Hill mine and the Springfield mine, which lies about four and three fourths miles a little west of south of Mineral Hill, there are indications of the existence of a mineralized belt. About one-half mile south of Morgan Run on the state road there is exposed in the side of the road the weathered outcrop of a band of amphibole schist (about 150 feet wide at this point), from which a little copper was taken where prospect holes were opened in the woods southwest of this point. No more exposures can be seen until the Carroll mine, three miles to

⁴ *Op. cit.*, p. 43.

EXPLANATION OF PLATE X.

FIG. 13. *The Mineral Hill Mine.* ($\times 77$.) Polished section. This section shows sphalerite (*se*) replaced by chalcocite (*cc*) along cleavage cracks. Note the numerous inclusions of chalcopyrite (*cp*) and bornite (*b*).

FIG. 14. *The Mineral Hill Mine.* ($\times 60$.) Polished section. Typical section showing alteration of chalcopyrite to chalcocite (*cc*) in the Mineral Hill ore.

FIG. 15. *The Liberty Mine.* ($\times 370$.) Polished section. Intergrowth of bornite (*b*) and chalcocite (*cc*). An etched section of this piece of ore shows that the fingers of bornite are parallel to the cleavage lines in the chalcocite crystal, a fact which suggests that the bornite is younger than the chalcocite, or at least contemporaneous with it.

FIG. 16. *The Liberty Mine.* ($\times 400$.) Polished section. Graphic intergrowth of bornite (*b*) and chalcocite (*cc*). The cleavage lines in the chalcocite show the relatively large size of the crystal.

FIG. 17. *The Liberty Mine.* ($\times 320$.) Polished section. Alteration of bornite to chalcocite along crevices and at the contact with gangue (*G*) (barite). Note the fuzzy contact. This is due probably to the formation of minute covellite crystals.

FIG. 18. *The New London Mine.* ($\times 47$.) Thin section of the "schistose ore." Chalcocite (black) surrounding and replacing calcite grains. Note the large crystals of calcite showing bent twinning lamellæ. The low index mineral (light) surrounded by chalcocite is quartz.

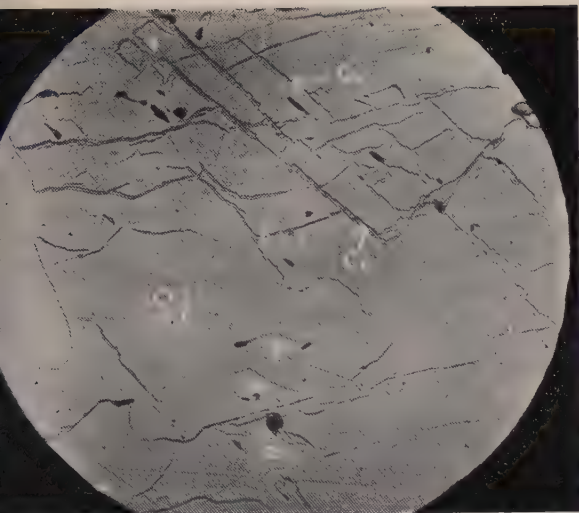


FIG. 13.

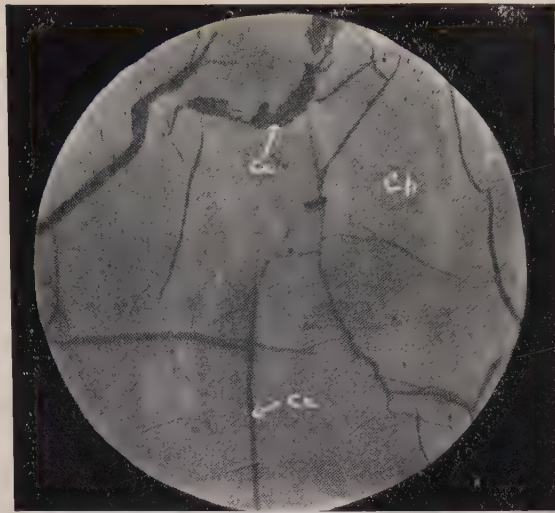


FIG. 14.

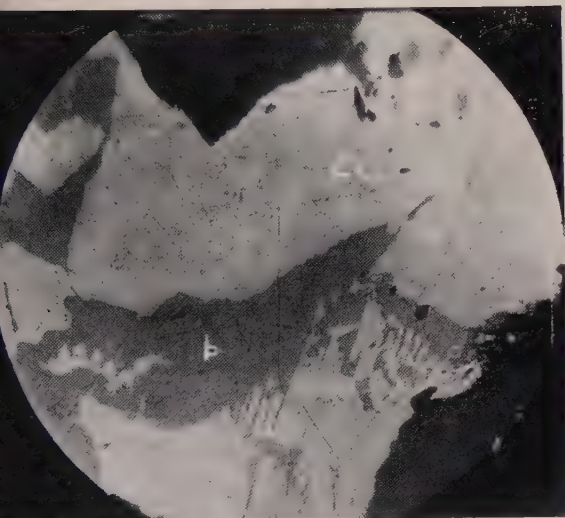


FIG. 15.

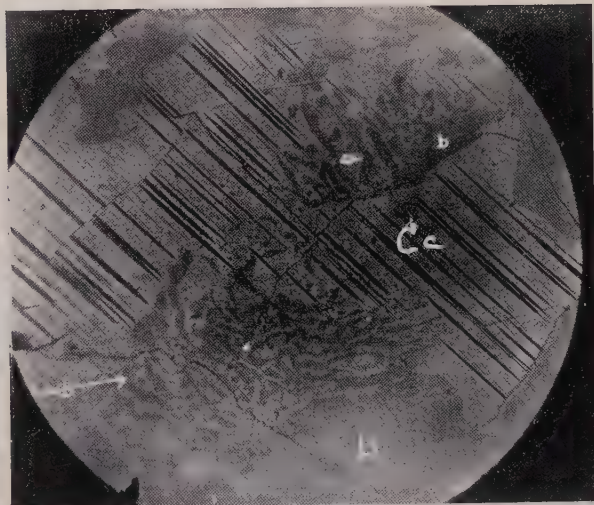


FIG. 16.

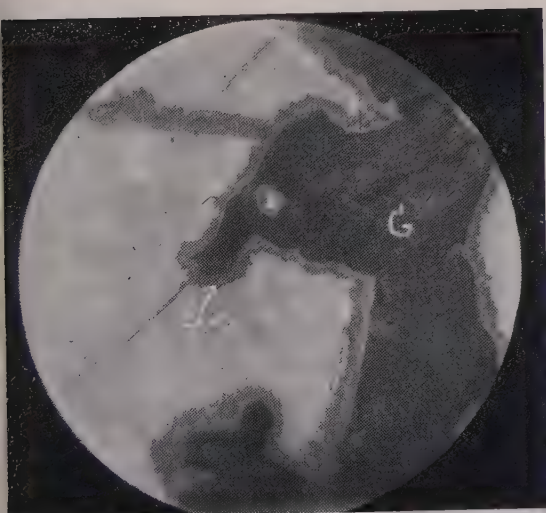


FIG. 17.

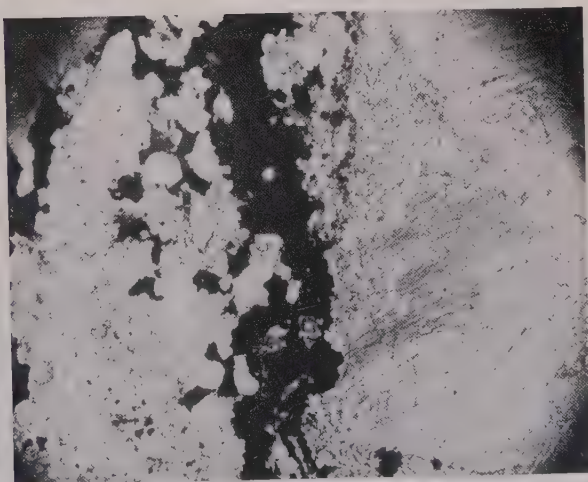


FIG. 18.

the southwest, is reached. The Carroll mine is on the north side of Piney Run about one fourth mile west of the state road, and consists of several small openings exposing a banded quartz-specularite rock. This mine was never of importance as a copper mine. One half mile a little west of south of the Carroll mine lies the Springfield deposit, one of the most important in the days of copper mining in Maryland. Since, however, this mine does not afford material for study under the metallographic microscope, a discussion of the ore occurrence will be omitted.

Genesis of the Carroll County Deposits.

Genesis.—None of the early writers who have described the eastern Carroll County deposits have discussed their genesis. The similarity of the deposits and their confinement to a narrow belt, however, were early recognized. Ansted⁵ in 1854 mentions these facts, and Weed⁶ in 1911 speaks of the deposits as occurring along "a copper-bearing fissure vein . . . [that] is distinctly traceable across Carroll County."

The first question to be settled, then, concerns the nature and extent of this belt in which the copper deposits are found. The following facts about it are known:

1. The copper deposits are found along a line whose strike is approximately that of the schistosity of the country rock.
2. The character of the rock found on the various mine dumps and in outcrops at the mines and in the state road south of Morgan Run, where the line was projected to cross, differs markedly from the prevailing country rock.
3. A dike of highly metamorphosed gabbro is found along a projected continuation of the line to the north of Finksburg, and can be traced for several miles.
4. Copper stains are reported from Blue Mount, sixteen miles northeast of Finksburg still on the strike of the line, and finally,

⁵ Ansted, D. T., "On Some Copper Lodes near Sykesville in Maryland," *Quart. Jour. Geol. Soc.*, London, Vol. XIII., pp. 242-245, 1857.

⁶ Weed, W. H., "Copper Deposits of the Appalachian States," *Bull.* 455, U. S. Geol. Survey, 1911, pp. 62-65.

5. Copper ores are not known anywhere in eastern Carroll County except along the line described.

It appears, then, that this is a line of structural weakness along which intrusion could take place or ore-bearing solutions travel. That such lines exist is shown by the occurrence, farther west, of a Triassic diabase dike, which can be traced practically without break across the state.

As has been pointed out above, the rocks in the vicinity of the mines are probably altered basic intrusives which were injected along this line of weakness before or during the time intense dynamo-metamorphic changes were going on. Some time after regional metamorphism ceased, pegmatitic material was injected into the country rock, and, at the Patapsco mine, into the altered intrusives. That the pegmatite is later than the schistosity is clearly shown by its relation to the schists as well as by its relatively fresh and unsqueezed condition as revealed by the microscope. After the pegmatitic injection came extensive epidotization followed by the deposition of the ore minerals.

It is proper, now, to see what evidence the minerals associated with the ore deposits have to offer concerning the conditions under which ore deposition took place. The chief rock-forming minerals present—biotite, hornblende, zoisite, and epidote—may all be the product of regional metamorphism, and hence would be expected to add nothing to a knowledge of the conditions under which the ore formed. Epidote, however, although probably part of it is due to regional metamorphism, is found replacing feldspar in the pegmatitic material, and is, therefore, later than the schistosity of the rocks. Aside from being a product of regional metamorphism, epidote, according to Emmons,⁷ may be present in contact metamorphic deposits, in the weathered zone, and in deposits of the deep-vein zone. There is no evidence that these deposits are contact metamorphic deposits; and it has been shown that the epidote is earlier than the ore minerals, and gives no evidence of being due to weathering. The conclusion, then, is that the epidote is the product of the deep-vein zone.

⁷ ECON. GEOL., Vol. III., 1908, p. 619.

Of the copper-bearing minerals and their accessories (sphalerite, magnetite, and specularite), bornite, chalcopyrite, and sphalerite may occur in deposits of moderate depths, as well as in those of great depth; but magnetite and specularite are found only in veins of the deep zone.

The absence of fissure-filling and of crustification in the vein material and the presence of extensive replacement phenomena give further evidence of a deep-seated origin for these ores.

The source of the ore-bearing solutions can only be surmised, but in view of the fact that pegmatites are common throughout the region, and that large granite masses occur east and south of the belt, it seems probable that the ore-bearing solutions had their origin in a cooling granite magma. Since the granitic intrusives in Maryland are probably of two or more periods whose ages have never been determined definitely, it is impossible to say in what geologic period mineralization took place. Some of the intrusives are clearly pre-Cambrian, while others show no influence of the metamorphic action which produced the general schistosity of the region. Since rocks as young as the Ordovician are schistose, the final granitic intrusions may be Devonian or younger, and it is with these late intrusions that these ore deposits seem to be connected.

The ores, then, of the eastern Carroll County belt occur in replacement veins which were formed at great depth, and whose time of formation was after the country had undergone intense regional metamorphism. The ore-bearing solutions were ascending solutions, and probably had their origin in the granitic magma which underlay the region to the east.

The Frederick County Mines.

In the eastern part of Frederick County, about twenty miles west of the Carroll County copper belt just described, is another region in which copper mining was carried on. Two mines in this district—the Liberty mine and the New London mine—were once of considerable importance in the state as copper producers. Two other deposits—the Dolly Hyde and the New Windsor de-

posits—were considered promising when they were opened, but later work did not fulfill their early promise. One lead mine—the Mountain View Lead Mine—was opened, but was soon abandoned.

There is a marked difference in the mode of occurrence between the Frederick County ores and those of eastern Carroll County. Some of the characteristics of the Frederick County occurrences are as follows:

1. The Frederick County copper ores are scattered widely throughout the region of eastern Frederick County.
2. Many limestone outcrops occur showing copper stain, or thin stringers of copper minerals.
3. The ores are apparently confined to the vicinity of a contact between these limestones and the adjacent schists.
4. The copper ores occur as pockets or stringers in the limestones.
5. The ore minerals are bornite and chalcocite with minor amounts of chalcopyrite.
6. The gangue is calcite, quartz, and barite.

Some miles to the west of the Frederick County mines, the narrow belt of Triassic rocks that extends southward from New York cuts across the state. Traces of copper have been reported in these rocks from a number of places, but none of the deposits ever looked tempting enough to be developed. Still farther west, on the eastern side of South Mountain, copper again occurs accompanying the pre-Cambrian lava flows that form the eastern part of the mountain. No work has been done in Maryland on these deposits, although a number of mines have been opened at one time or another just north of the state line in Adams County, Pennsylvania.

Liberty Mine.

Location.—The Liberty mine is situated about five and three fourths miles southwest of Union Bridge—a town on the Western Maryland Railroad, forty-five miles northwest of Baltimore—on the Copper Mine road, one mile west of where it crosses the Liberty-Union Bridge turnpike.

A comparatively large mine dump and an old mill partly dismantled and in a complete state of decay shows the location of the mine property. Underground work has been carried on at two places on the property; one place known as the Old Workings, and the other as the New Workings. The Old Workings have completely caved, and are hence no longer accessible; the New Workings (last worked about 4 years ago) are only partly accessible.

Geology.—The Western Division of the Piedmont, in which the Frederick County deposits lie, is characterized by quartzites, schists, and limestones.⁸ The quartzites are undoubtedly of sedimentary origin, consisting as they do of water-worn pebbles (varying in size from .1 inch to .3 inch in diameter). The schists are of both sedimentary and of igneous origin. The sedimentary schists are gray and sandy, or soft, dark phyllites; the igneous schists are metamorphic equivalents of acid and basic tuffs and lavas, showing very often an amygdaloidal structure. The basic rocks alter to greenstone, and seem to be more common in the southern part of the district. The limestones are found in long narrow bands in the schists; or they outcrop in small irregular patches whose geological significance is difficult to explain. Many theories concerning the structure of this portion of the Piedmont have been advanced, but none has been generally accepted.

The Liberty deposit occurs at the top of a broad flat hill, and as a consequence there are no exposures of the country rock other than those seen in the mine. A few hundred yards to the west of the mine conglomerate float was found in the field; at the mine limestone is exposed; and a few hundred yards to the east of the mine, schist occurs along the road. Here, as at most of the other localities already described, the mine dump has to be depended on to show the character of the rock in the immediate vicinity of the deposit. It is composed largely of dolomitic limestone, which is sometimes a pure carbonate, and at other times a mixture of limestone and schist. Purple, green,

⁸ "The Limestones of Maryland," E. B. Mathews and J. S. Grasty, Md. Geol. Survey, Vol. VIII., pp. 350 et seq.

and gray schists are also found. The purple schist is a soft, thinly-bedded rock that shows amygdaloidal structure, and under the microscope is seen to be an altered effusive rock probably of acidic type. The soft light-green schist, apparently, is derived from the impurities in the limestone with which it is closely associated. The gray schist is amygdaloidal, and is a metamorphosed effusive similar to the purple schist just described. The limestone is a fine-grained dolomite cut by numerous stringers of coarse-grained calcite.

Description of Ore.—The copper-bearing minerals found at the mine are bornite, chalcocite, chalcopyrite, and malachite. Bornite and chalcocite are present in about equal amounts; chalcopyrite is rare; and malachite although widespread is of no importance commercially. Thin sections of the ore show the copper minerals to be the latest minerals present, since they replace the dolomite, and enter along cleavage cracks of the large calcite and barite crystals present. Quartz replaces calcite and dolomite, but is earlier than the copper minerals.

The ore minerals present in the polished sections are chalcopyrite, bornite, and chalcocite. All occur as primary minerals. Chalcopyrite and chalcocite are also secondary.

Primary⁹ Chalcocite.—Primary chalcocite seems to have been the earliest of the ore minerals to crystallize. Etching brings out the fact that it consists of large crystals which include bornite. This bornite also seems to replace the chalcocite to some extent. Fig. 15, shows bornite with stringers arranged parallel to the cleavage lines (brought out by etching, but not shown in plate). Bornite is seen, too, in stringers between the chalcocite crystals. At times, however, the relation between bornite and chalcocite shows that they are, in some cases, probably contemporaneous; for some excellent graphic intergrowths were noted (Fig. 16).

Bornite and Chalcopyrite.—Bornite and chalcopyrite are present in typical primary intergrowths. Later chalcopyrite is pres-

⁹ *Primary* is used here and below with the connotation of deposition by heated ascending solutions; *secondary*, below, of deposition by cold descending solutions.

ent to a small extent, occurring along cleavage lines of the bornite. The relations between bornite and chalcopyrite are similar to those already described under the Patapsco ores.

Secondary Chalcocite.—Secondary chalcocite is found replacing both bornite and chalcopyrite along cracks, and at contacts with the gangue minerals. This, too, has been described above. In the sections containing the primary chalcocite and the primary bornite, there is a form of chalcocite present that is of a deeper blue than the ordinary chalcocite. Graton and Murdoch¹⁰ mention the occurrence of this mineral and make the suggestion that it is a mineral distinct from chalcocite. In the section examined, the mineral was seen in large amount intimately mixed with primary chalcocite. Its exact nature, however, could not be determined.¹¹

Gangue Minerals.—Barite, calcite, and quartz occur as gangue. The barite and calcite are in well formed crystals; the quartz is in grains intimately mixed with the ore. The barite and calcite are earlier than the ore minerals, but the intimate relations between quartz and ore minerals make it appear as if some of the silica came in with the ore-bearing solutions, and was deposited as quartz at much the same time as those minerals.

New London Mine.

Location.—The New London, or Linganore, mine is about four and one half mile east of south of the Dolly Hyde mine, and about three and one half miles north of Monrovia, a station on the main line of the Baltimore and Ohio Railroad, fifty miles west of

¹⁰ *Op. cit.*, pp. 47, 48.

¹¹ *Cf.* "The Sulphides of Copper," by E. Posnjak, E. T. Allen, and H. E. Merwin, *ECONOMIC GEOLOGY*, Vol. X., No. 6, September–October, 1915. The authors of this article call attention to the frequent occurrence of solid solutions of cupric sulphide in cuprous sulphide associated with chalcocite. These solid solutions are characterized by a blue color. The blue mineral in the section studied may be such a solution. *Cf.*, also, "Observations on Certain Types of Chalcocite and Their Characteristic Etch Patterns," by C. F. Tolman, Jr., *Bulletin of the American Institute of Mining Engineers*, February, 1916. The "blue chalcocite" is thought by Tolman to represent a transition type in the replacement of bornite by chalcocite.

Baltimore. This mine is still worked, although very spasmodically.

Geology.—The New London deposit is in the same general geologic province as the Liberty deposit. The rock types are the same, although greenstones are much more prominent in the neighborhood of the New London mine. The deposit is found in an impure limestone, which outcrops on the side of a rather steep hill. The hill is capped by a heavy quartzite, and the slopes are made up of gray schist, phyllite, greenstones, and impure limestone, all of which appear to dip to the west and hence under the quartzite. The strike of the beds near the mine is roughly a little east of north. Rock exposures are not frequent, and are difficult to interpret. At least one well-marked fault can be seen a short distance north of the mine, and there are facts that suggest other faulting. In the mine itself a fault cuts out the ore body entirely, and frequent offsetting of the vein shows still other movements.

Thin sections were made of some of the rocks found in the vicinity of the mine. The greenstone was seen to consist largely of fine-grained epidote with numerous inclusions of specularite, cut by small stringers of calcite accompanied by plagioclase. The original structure of the rocks is obscured; but its chemical composition, as revealed by the minerals present, and its similarity to rocks from the region to the west, where their nature is definitely known,¹² leave little doubt that the greenstones are altered basic effusives. A specimen of schist from the field north of the mine is seen under the microscope to be a fine-grained amygdaloidal rock showing marked flow structure. The groundmass of the rock consists of a very fine-grained aggregate of minerals which are too small to be determined with certainty, but which, on account of their general low index and double refraction, suggest quartz and feldspar. The rock corresponds closely to some of the aporhyolites from the South Mountain region described by F. Bascom. The impure limestone from the mine itself is a contorted schist with bands of limestone and soft gray phyllite. Under the microscope the bands of limestone are seen to

¹² Bascom, F., Bull. U. S. Geol. Survey, No. 136.

consist of long narrow crystals of calcite, without crystal boundary, ranged side by side with their long axes parallel; the phyllite bands are made up in large part of sericite with numerous inclusions of specularite.

Type of Deposit.—The New London deposit belongs in the same general class with the Liberty deposit, although it occurs in somewhat different form. At the Liberty mine, it will be remembered, the ore was found in stringers or bunches in rather pure limestone. At the New London mine the ore is in a fissure cutting across an impure limestone which has been mineralized. As a consequence of the impurities in the limestone, the ore is of two general types: (1) a massive ore called "typical 'vein' ore" by Butler and McCaskey¹³ and (2) a schistose ore (Fig. 18). The massive ore occurs where the limestone is relatively pure, and consists of masses of chalcocite with gangue calcite and quartz in the limestone. The schistose ore occurs where the limestone consists largely of phyllite, with narrow bands of pure limestone, and represents the replacement of some of these small limestone bands by chalcocite.

Description of Ore.—The ore minerals observed in the polished sections were chalcocite and bornite. Chalcopyrite is reported from this locality by Weed, but none of it was observed. Chalcocite predominates, bornite being present only in small amounts. An etched sample of the ore shows the chalcocite to be in rather large individual crystals. In some cases it appears to be contemporaneous with the bornite, but in other cases the bornite seems to have come out of solution later than the chalcocite, since its disposition at these places seems to be entirely dependent on the previous existence of the chalcocite crystals. This condition is similar to that already described under the ores of the Liberty mine. No chalcocite that is undoubtedly secondary was seen. Although the thin sections show that some quartz is earlier than the ore minerals, the intimate relations existing between chalcocite, bornite, and quartz, as shown by the polished sections,

¹³ "Copper Ores of the New London Mine," *Bull. Amer. Inst. Min. Eng.*, July, 1914.

make it very probable that some of the quartz was contemporaneous with the ore-bearing minerals.

Genesis of the Frederick County Deposits.

Genesis.—The first hypothesis as to the origin of the Frederick County copper deposits is one proposed by Weed¹⁴ in 1911. He says:

“The copper occurs in or alongside of masses of dolomitic limestone and marble included in micaceous schist. . . . In most of the area from New London northeastward belts of marble . . . lie east of the greenstone. The ores appear to be confined to these marbles and to the schists alongside of them, occurring either along the contact or in the fractured rock itself, as, for example, in the recent workings of the Liberty mine.

“The meager facts cited would not warrant any generalizations were it not for the frequent presence of copper in the greenstone belt from Pennsylvania to the Carolinas. It is believed that this rock furnished the copper for the solutions and that the limestone and its graphitic matter supplied the precipitant for the copper.”

Weed does not say whether he considers the copper to have been concentrated by cold atmospheric waters, or by warm waters, when the greenstone was first poured out as a lava and was still in a heated condition. The igneous rocks at the Liberty mine, as a matter of fact, are practically all acid intrusives similar in most respects to the aporhyolites described from the South Mountain region. Greenstones were not noted in the immediate neighborhood of the deposit.

The ore minerals, bornite and chalcopyrite, and bornite and chalcocite, are seen in the polished sections to form typical primary intergrowths as illustrated by Graton and Murdock in their excellent paper on “The Sulphide Ores of Copper.”

The instability of the bornite is shown, in the sections from the Liberty mine, by its alteration to secondary chalcocite and secondary chalcopyrite. The examples of graphic intergrowth of bornite and chalcocite seem to leave no doubt as to the primary

¹⁴ Bull. U. S. Geol. Survey, No. 455, 1911, p. 62.

nature of these ores. Emmons¹⁵ says the following about graphic intergrowth of bornite and chalcocite:¹⁶

"It appears possible from these relations that under certain conditions chalcocite is deposited as a primary mineral by hot ascending waters. The intergrowth of the copper sulphide in graphic-like pattern is a feature that is difficult to explain on the hypothesis of an origin from descending sulphate waters. . . . It appears probable that under conditions where the concentration of iron is low in the solutions chalcocite may form as a primary mineral instead of chalcopyrite, which is the commoner primary ore."

The presence of calcite, quartz, and particularly barite as gangue, together with the absence of magnetite, specularite, and other high-temperature minerals, indicates (on the assumption that the ore and gangue are due to hot ascending solutions) that the deposits were formed at moderate depth.

The location of many of these deposits at contacts is probably due simply to the fact that the contact offered a path along which the solutions could move more readily, and also to the fact that the limestone furnished the agent for precipitating the copper minerals. The deposit at New London is not located at a contact, but along a fissure or a fault which cuts across a limestone band.

The derivation of these ore-bearing solutions is not certain, but it seems probable that the deposits belong to the same metallo-

¹⁵ Bull. U. S. Geol. Survey, No. 259, p. 107.

¹⁶ Cf., however, "The Secondary Sulphide Enrichment of Copper Ores with Special Reference to Microscopic Study," by A. F. Rogers, *Min. and Scien. Press*, October 31, 1914, pp. 680-686. Rogers considers the so-called graphic intergrowths of bornite and chalcocite to be a criterion of *upward* chalcocite enrichment. Cf., also, "The Origin and Occurrence of Certain Crystallographic Intergrowths," by J. Segall, *ECON. GEOL.*, Vol. X., No. 5. Segall, referring to some so-called graphic intergrowths of bornite and chalcocite, described and illustrated in the above article, says, "it is inferred that intergrowths of sulphides may be formed by secondary processes. These intergrowths may have a close resemblance to what are known as contemporaneous intergrowths." Segall's explanation of the formation of these intergrowths would hardly apply in the case illustrated in Fig. 16, since here the chalcocite on etching develops cleavage lines in one direction only (orthorhombic cleavage), and does not show the intersecting cleavage (isometric cleavage) that seems to be the foundation upon which his argument rests.

genetic epoch as do the Carroll County ores. Both are associated areally, but not genetically, with greenstones. The type of ore-bearing solutions in both districts was apparently similar, although disposition took place under somewhat different conditions—deep-seated in Carroll County, and moderate to shallow in Frederick. Finally, mineralization in both cases is shown to have occurred after the development of schistosity—*i. e.*, in post-Ordovician times.

Thin sections of the ore show that mineralization took place after the major dynamic movements that rendered the rock schistose. It has been shown that Ordovician rocks are included in the schists of the Piedmont region: hence the date of mineralization can be put in post-Ordovician times.

SUMMARY.

Copper has been mined in Maryland from before 1760 to the present. The industry, though small in production, was of considerable importance prior to the middle of the nineteenth century, but at present it is insignificant and the production negligible.

All the commercially utilized deposits occur in the metamorphosed complex of the Piedmont, where the country rocks include metamorphosed sediments and early eruptives with later less metamorphosed eruptives. On the east, associated with the Baltimore County and eastern Carroll County deposits, deep-seated igneous masses predominate; while on the west, associated with the Frederick County deposits, metamorphosed acid and basic lavas and tuffs are abundant.

The eastern Carroll County deposits, comprising the Finksburg, the Mineral Hill, and the Springfield deposits, lie along a definite structural line of weakness that can be traced for many miles across the state. The country rock of the region is phyllite and quartz mica schist. A large granite intrusive lies near the southern end of the copper belt, and pegmatite dikes are common throughout the region. Altered basic intrusives are found along the line of weakness, and it is with these that the

copper ores are really associated. The ore occurs in replacement veins roughly conformable in strike and dip with the country rock. The ore minerals are chalcopyrite, bornite, carrollite, chalcocite, and covellite, and associated with these are sphalerite, magnetite, and specularite. Chalcopyrite, bornite, sphalerite, magnetite, and specularite form primary intergrowths; chalcocite and covellite are always secondary, replacing all the minerals present except magnetite and specularite. The gangue minerals present are hornblende, biotite, epidote, and feldspar, all of which are partly replaced by the ore minerals. The paragenesis of the ore minerals and associated minerals is magnetite, hornblende, biotite, epidote, quartz, feldspar, magnetite, carrollite, sphalerite, chalcopyrite and bornite, secondary chalcopyrite, covellite, chalcocite—magnetite being the oldest.

The varieties and relationships of these minerals present in the deposits indicate that deposition took place from hot ascending solutions, and at considerable depth. Secondary alteration to chalcocite due to descending solutions has taken place along crevices in the ore, but is of little importance. Deposition was shown to have taken place after the period of metamorphism of the region, probably in post-Ordovician time. That the source of the ore-bearing solution was probably the granitic magma from which the pegmatitic material came, is indicated by the presence of a large granitic mass near the copper belt, and by the general agreement in age of the ore deposition and the intrusion of the granite.

The Frederick County deposits, comprising the Liberty and the New London deposits, are confined to limestones at or near their contact with other rocks. The country rock of the region consists of metamorphosed sedimentary rocks, and altered acid and basic extrusives. The ores occur as pockets and stringers in limestone, or as replacements of calcareous bands in impure limestone. The ore minerals are chalcopyrite, bornite, chalcocite. Quartz, calcite, and barite form the gangue minerals. Chalcopyrite and bornite show primary relationships; bornite and chalcocite occur in graphic intergrowths, and are in part prob-

ably contemporaneous in origin. Secondary alteration to chalcocite is prevalent, but is not important. The paragenesis of the minerals (in the order of deposition) would be calcite (?), barite (?), quartz, chalcocite, chalcopyrite and bornite, secondary chalcopyrite, secondary chalcocite. Some quartz is probably contemporaneous with the deposition of the ore minerals.

The character of the minerals and their associations thus point to deposition from hot ascending waters at moderate depth. Mineralization apparently took place after the metamorphism of the region. The source of the ore-bearing solutions is not certain, but it seems probable that the mineralization was contemporaneous with that in Carroll County, and that the ore-bearing solutions probably have a common source. There is no evidence that the solutions were derived from the greenstones of the region with which the deposits are frequently associated.

VITA

Robert Milton Overbeck was born in Baltimore, Maryland, January 23, 1887. He graduated from the Baltimore City College in 1906, and entered upon his collegiate work in the Johns Hopkins University, from which institution he received his A. B. in 1909.

The following two years (1909-1911) were spent in teaching.

In October, 1911, he entered the Geological Department of the Johns Hopkins University, and pursued graduate work there. During the years 1912-1913, 1913-1914, he held Maryland Scholarships; and during the year 1914-1915 he held a University Fellowship in Geology.

In the summer of 1912 he did geological work in Western Maryland under Dr. Charles K. Swartz for the Maryland Geological Survey. The summer of 1913 was spent as assistant to Dr. George Curtis Martin in work for the U. S. Geological Survey in the Matanuska coal field of Alaska. The following summer (1914) was spent in visiting Mesozoic localities along the coast and in the interior of Alaska as assistant to Dr. Martin.

The writer of this dissertation wishes here to express his sense of obligation to those who have aided and inspired him during his four years of graduate work—to Professor William Bullock Clark, to Professor Harry Fielding Reid, to Professor Edward W. Berry, to Professor Charles K. Swartz. In particular he wishes to thank Dr. Joseph T. Singewald, Jr., who proposed the subject of this investigation and who has been ever ready with assistance while the work was being carried on; and Professor Edward B. Matthews, who assisted in the study of the rock slides and who offered helpful suggestions in the interpretation of Piedmont geology.

